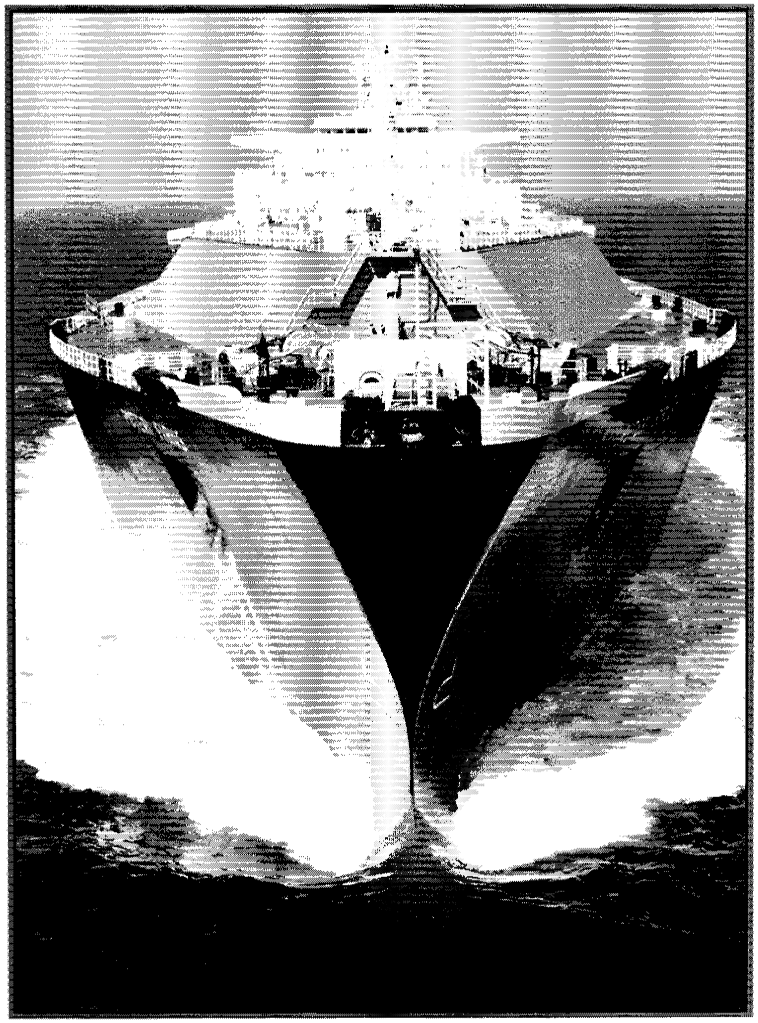
LNG Supply Chain Greenhouse Gas Emissions for the Cabrillo Deepwater Port: Natural Gas from Australia to California



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to Pam-e for her red-headed wisdom

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Contents

Cover: *Puteri Firus* sailing for Shell International Trading & Shipping, Alstom/Chantiers, shipbuilder, www.marine.alstom.com

LNG Supply Chain Greenhouse Gas Emissions,

In which natural gas from BHP Billiton's Scarborough offshore field is extracted, transported by subsea pipeline to the proposed Pilbara LNG plant near Onslow, Western Australia, where the gas is liquefied, shipped by LNG carrier to Cabrillo Deepwater Port offshore Ventura County, and finally combusted by SoCalGas' end-use customers in southern California.

Introduction

This report summarizes an analysis of greenhouse gas emissions from the entire supply chain as identified by BHP Billiton, the project's applicant, as the likely source of natural gas delivered as LNG to the Cabrillo Deepwater Port receiving terminal offshore Los Angeles, Malibu, and Oxnard, California. BHP has presented and the California State Lands Commission (CSLC) has reviewed what appear to be reliable estimates of most of the greenhouse gas emissions arising from start-up and yearly operation of the Cabrillo facility. No attempt was made by BHP or by the CSLC to include emissions from other critical links in the delivery chain from the production of natural gas in Australia through to its consumption by California gas customers. This interpretation of what constitutes greenhouse gases emissions arising from a proposed energy project is too narrow.

Climate Mitigation Services was commissioned by the Environmental Defense Center on behalf of the California Coastal Protection Network to fill this analytical gap. The Cabrillo Deepwater Port, as this analysis will show, is the source of only 1.5 percent of the full range of emissions from the supply chain summarized in this report.

What follows is an identification of the major segments of the supply chain as described by BHP in its *Construction Permit Application* and by the CSLC in its *Revised Draft Environmental Impact Report*. The report quantifies the pertinent emissions of greenhouse gases from each of these segments.

Study Objectives

This study's objective is to take a comprehensive view of a proposed new source of natural gas to southern California customers — the Cabrillo Deepwater Port — and estimate total emissions of greenhouse gases from the production of the delivered gas to its combustion by end-users. The Liquefied Natural Gas (LNG) receiving and re-gasification terminal is intended to supply 800 million cubic feet of natural gas per day (equal to the energy contained in ~7 million gallons of gasoline per day), according to BHP Billiton, the Australian multi-national energy and minerals company proposing to build the Cabrillo facility 14 miles offshore Ventura County.

BHP has estimated greenhouse gas emissions from the operation of the Cabrillo Deepwater Port as part of its permit application to the U.S. Coast Guard and the State of California. While the BHP application also estimates impacts on air quality, water discharges, land use, ocean bottom disturbances, etc., the purpose of the present analysis is to estimate emissions of greenhouse gases across the entire supply chain of natural gas — from its production platform offshore Western Australia and across the Pacific Ocean to California, including liquefaction and other significant emissions sources. Emissions from the combustion of the delivered natural gas by

California gas customers are also included (after deducting for minor non-fuel uses of natural gas). This allows a meaningful comparison of total supply chain emissions to those from the Cabrillo Port estimated by BHP Billiton in its *Construction Permit Application*.

Each emissions source and the methodology used to quantify them are fully documented in the appended spreadsheets. This report summarizes the major segments of the supply chain, the main sources of greenhouse gases in each segment, and quantifies emissions from each link in the chain that may, if BHP is successful, connect California's gas power plants and water heaters to a natural gas field offshore Western Australia.

This summary report cannot substitute for the details contained in the attached spreadsheets and their cell notes. CMS relies on BHP-supplied data when feasible, and upon industry practice and reasonable (and fully documented) performance indicators when estimating emissions beyond the limited scope of BHP's own estimates. Nonetheless, it is important to state clearly that the results summarized herein are *estimates* and are made without access to detailed engineering analyses only available to BHP, and in many cases are merely in the early planning stages.

It is not our purpose to attribute the entirety of the supply chain emissions to BHP. Rather, the purpose is to fully account for all the emissions attributable to the proposed project from start to finish, from production to combustion. Cabrillo is not isolated from the rest of the supply: it relies on Australian gas that has to be liquefied and shipped at considerable environmental and capital cost, and the gas supplied by the Cabrillo regasification plant will be burned in appliances and turbines in California. State agency officials and the California public cannot make an adequate assessment of the pros and cons of the proposed project without information on the broader scope. This study does *not* evaluate alternative means of delivering energy resources to California, and no recommendations for or against this project will be made.[1]

Both "high" and "low" estimates are calculated and fully documented in the attached set of worksheets and tables; we generally report the average of high and low in this summary. Note: CMS reports LNG and emissions in metric tonnes (1 tonne = 1.1023 short tons).

Boundary definition

This study identifies and quantifies all significant sources of greenhouse gas emissions inherently linked to BHP's delivery of natural gas to southern California. The boundary commences both temporally and geographically with the production of natural gas offshore Western Australia. Energy-related combustion and process emissions across the supply chain are within the boundary. The chain ends with the combustion of the delivered gas by California gas customers. The gases included in the inventory are carbon dioxide and methane from combustion sources, process emissions, and fugitive and/or vented sources.

Nitrous oxide and halocarbon emissions sources are *not* included, except for a minor amount of N_2O from the liquefaction plant.[2] Also excluded are emissions from the materials embodied in

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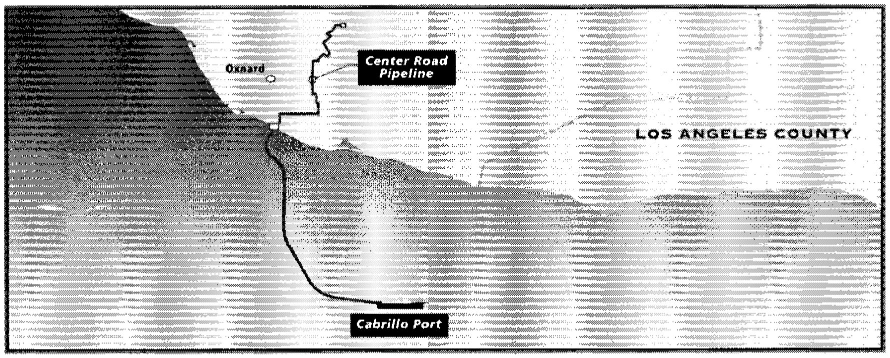
[1] The uses of BHP's delivered gas are numerous, and a detailed assessment would need to be done to adequately compare options such as domestic natural gas, hydrogen, renewable energy, end-use efficiency, or alternate sources of LNG. Interested readers might start with Hunt et al (2006) *Does California Need Liquefied Natural Gas?*

[2] Potential emissions of halocarbon leakage or off-gassing during the manufacture, installation, and use of insulation materials in cryogenic storage tanks, pipelines, and LNG carriers have not been quantified. The value chain contains on the order of 10^5 m^3 of insulation material. These include rigid foams (polystyrene, polyurethane, and phenolic resins) and bulk zeolites. Liquefaction plants typically use propane and/or mixed refrigerants; van de Graaf (2006).

the supply chain, such as the ~600,000 tonnes of steel built into production platforms, pipelines, liquefaction plant, fleet of LNG carriers, storage tanks, and the offshore Cabrillo facility.[3]

Energy consumption and emissions from shipyards, engine manufacturers, and the offices of naval architects and plant engineers are similarly outside the boundary, even though these emissions are at least partially attributable to the creation of the supply chain in question. Nor is travel by BHP managers from Perth included, or commuting to work by hundreds of Cabrillo Port construction workers (except for emissions from fuel used by crew boats). The emissions from manufacturing and towing the 200,000-tonne Cabrillo Port to its offshore site, or mooring it to the seafloor, are also excluded. Although omitted by BHP, CMS has estimated emissions from the construction of the pipeline connecting the Cabrillo facility to onshore gas utilities.



Location of the Cabrillo Deepwater Port facility. Source: California State Lands Commission (2006).

Supply chain description

In brief, the delivery of gas to southern California markets via the proposed Cabrillo Floating Storage and Regasification Unit (FSRU) is accomplished by transporting the gas produced from the offshore Scarborough natural gas field by a production platform on (yet to be built) through a 170-mile (280-km) subsea pipeline (yet to be built) to a large gas processing plant being planned near Onslow, Western Australia (population of 800).

This plant (yet to be built) would remove impurities and liquefy nearly 8 million tonnes of natural gas per year by chilling the gas, now mostly methane, to minus 259 °F. At this point it is liquefied natural gas (hereafter LNG), and its volume has decreased by a factor of 600, enabling it to be economically shipped in a fleet of LNG carriers (yet to be built) across the Pacific Ocean to California, where it will be re-gasified by adding heat to the LNG in the Cabrillo FSRU (yet to be built), and piped to shore in a planned pair of 24-inch pipelines. The LNG business is not new; in fact Japan has imported LNG for power generation and heating needs for decades, including from an LNG plant in Kenai, Alaska.

[3] CMS does *not* include the roughly estimated 700,000 tonnes of CO_2 from the fabrication of 570,000 tonnes of steel at ~1.24 tonne CO_2 per tonne of steel. Emission factor from Delucchi (2003b). See Table 10 in the worksheet folio.

Where do emissions come from? Carbon dioxide, the principal greenhouse gas, is released as an essential byproduct of combustion: it's the high-temperature combination of hydrocarbons in the fuel — natural gas is mostly methane (CH_4), which is three-quarters carbon and one-quarter hydrogen by weight — with oxygen in the air that releases carbon dioxide and additional heat. Carbon dioxide comprises 94 percent of the total supply chain's emissions — nearly all of the CO_2 from fuel combustion — with methane the remaining six percent.

Every segment of the supply chain emits greenhouse gases. Liquefaction plants use enormous amounts of energy to generate power and run compressors that chill the natural gas to below its boiling point. Production platforms, pipelines, and the Cabrillo FSRU's re-gasification units are all energy-intensive, which essentially means that large quantities of fuels (mostly natural gas) are converted into CO_2 and emitted to the atmosphere. Production platforms and gas processing facilities routinely flare some of the throughput gas, or flash gas, chiefly for safety reasons, and the CO_2 from flares are estimated. Also, CO_2 is typically produced with natural gas, although the gas from Scarborough is reportedly very low in CO_2 (~1 percent).[4] Most of this CO_2 must be removed from the natural gas feed at the liquefaction plant and is vented to the atmosphere along with nitrogen, sulfur, helium, and other contaminants.[5] LNG carriers use marine diesel fuel and/or LNG boil-off gas for propulsion, with substantial CO_2 emissions for the trade route across the Pacific Ocean. Each of these supply chain segments will be described and quantified below.

Carbon dioxide represents 84 percent of total U.S. greenhouse gas (GHG) emissions, methane emissions comprise 9 percent, and nitrous oxide and various halocarbon gases the remaining 7 percent. Methane is important in the supply chain insofar as methane routinely leaks from gas pipelines, storage tanks, compressors, valves, flanges, and seals; methane is also directly vented from the gas processing plant. While routine leaks and vents are not large in terms of mass flow, methane is a greenhouse gas 23 times more powerful than CO_2 per unit mass. Finally, not all of the methane is fully combusted when gas is burned, and these quantities must also be counted.

Overall results

BHP adequately estimated emissions of greenhouse gases arising from the start-up and operation of the proposed Cabrillo Deepwater Port, the energy and emissions from the unloading of ~2.2 LNG carrier berthings per week, emissions from fuel used by the Cabrillo receiving terminal's tugs, tenders, and crew boats, and the main emissions source at Cabrillo: natural gas used in the FSRU's re-gasification units. BHP's estimate totals 261 tonnes of CO_2 per year, including a small amount of methane from incomplete fuel combustion.[6]

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[4] BHP has indicated that Indonesia is an alternate source of natural gas. The gas field has not been identified, nor has the gas been characterized. Thus it cannot be ascertained if the source gas is higher in carbon dioxide content than the gas from Scarborough. CMS has not modeled the supply chain emissions from this secondary source.

[5] CO_2 can be captured and re-injected into oil or gas field for re-pressurization and enhanced recovery, or otherwise sequestered away from the atmosphere. BHP has not, to our knowledge, investigated such opportunities to reduce project emissions anywhere along the supply chain. Nor do we know if BHP has signed a Greenhouse Challenge Co-operative Agreement with the Commonwealth Government. Western Australia does require an emissions mitigation plan, and greenfield projects such as Pilbara are subject to environmental and emissions guidelines. See Chiu (2002), Office of Environment and Heritage (2003), and BHP Billiton Petroleum (2005).

[6] BHP omits estimating methane leakage from the FSRU ("since fugitive leaks from the FSRU process equipment will be composed of primarily methane, they are not regulated by permit or source-specific requirements," and are thus excluded, BHP (2005), section 3.6). The BHP permit application also omits emissions from fuel consumed in construction of the mooring facilities and laying the pipeline from the FSRU to onshore natural gas infrastructure. CMS has made a rough estimate of fuel consumed and added the resulting emissions to the Cabrillo start-up and annualized into the supply chain operating emissions with a 25-year time horizon.

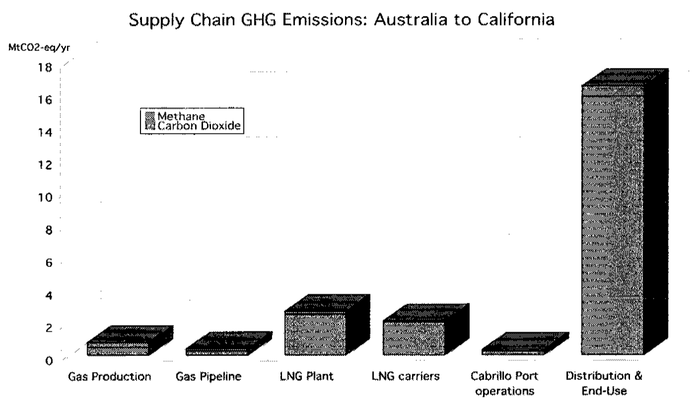
Table 1: Supply Chain emissions (average of low and high estimates)[7]

Supply-chain segment	Methane	Carbon Dioxide	Total	Percent
	thousand tonnes of CO_2-eq			
Gas production (Scarborough)	297	494	791	3.5
Gas pipeline to Pilbara LNG	135	264	399	1.7
Liquefaction plant at Onslow	175	2,512	2,687	11.8
LNG carrier fleet, Australia → California	47	2,048	2,095	9.2
Cabrillo Deepwater Port Operations	85	261	346	1.5
Cabrillo Start-Up (annualized, 25 yrs)	negl	0.4	0.4	0.0
Ultimate gas distribution & combustion	650	15,852	16,502	72.3
Total supply-chain GHG emissions	1,389	21,434	22,823	100.0
Percent	6.1	93.9	100.0	

Note: BHP Billiton's estimate of annual emissions at Cabrillo totals 261 thousand tonnes CO_2-eq (288 thousand tons CO_2-eq). Note that the table is in metric tonnes (1 tonne = 1.1023 tons).

BHP's estimate of emissions from the Cabrillo Deepwater Port operations represents 1.5 percent of the supply chain emissions as estimated by Climate Mitigation Services (Table 1). Emissions from Cabrillo operations are significant, especially in terms of local air quality if not global warming, but clearly pale in comparison (by a factor of 66 to 1) to emissions from the other elements of the supply chain required for gas delivery to southern California. The major component is, not surprisingly, combustion of the delivered fuel. Compared to the emissions from end-use combustion of the gas — which is a common measure of the global warming contribution of natural gas — the rest of the supply chain emits an additional 44 percent.[8] Methane is 6.1 percent of the total. The energy-intensive liquefaction plant and the LNG carrier "pipeline" across the Pacific emit ~twelve and nine percent of total emissions, respectively.

Figure 1: Supply Chain Emissions (average of low and high estimates)



[7] CMS has estimated each supply chain segment in a range. The table averages the high and low estimates.
[8] This fraction is derived as follows: the supply chain total divided by CO_2 from "Gas distribution & combustion:" 22.82 million tonnes of CO_2-eq ÷ 15.85 $MtCO_2$ = 1.440, or 44 percent "adder" to end-use combustion alone.

SUPPLY CHAIN SEGMENTS AND EMISSIONS ESTIMATES

Natural gas production at Scarborough offshore gas field

According to BHP's plans as stated in its *Construction Permit Application*, natural gas will be produced from the Scarborough subsea gas field 270-km northwest of the Pilbara Coast of Western Australia. The field is jointly owned by BHP and ExxonMobil, lies at depth of 900 m, was discovered in 1979, is shut-in (that is, there is no production facilities in place), and contains an estimated 8 trillion cubic feet (Tcf) of gas reserves. This reserve estimate is under review.[9]

All of the elements of the proposed supply chain between Scarborough and Cabrillo will use natural gas to fuel pipeline compressors, run generators at liquefaction plants, fuel engines onboard the LNG carriers, re-heat the cryogenic fluid in the Cabrillo re-gasification units, etc. Since BHP proposes to deliver 800 million cubic feet (0.8 Bcf)[10] per day to SoCalGas, our first task is to estimate the total amount of gas production required. This detailed analysis is summarized in Table 2 below. Suffice it to say here that the total annual production is not 292 billion cubic feet (800 million cf/day times 365 days per yr) but 379 Bcf/year in order to cover the delivery rate and the supplementary gas requirements. While it may be the case that BHP's production plans cannot satisfy this 30 percent higher production rate, this is not really material. The objective is to estimate total emissions, and whether it is produced at Scarborough or elsewhere matters less than the total quantity involved.[11]

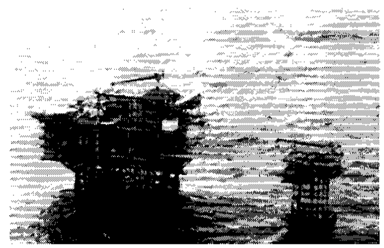


Table 2. Total gas production required for each segment and supply chain total

Segment	Million cf/day	Billion cf/yr	Million tonnes/yr
Production at Scarborough	21	8	0.17
Pipeline to Pilbara	13	5	0.10
LNG plant	103	37	0.81
LNG Carrier fleet	88	32	0.69
Cabrillo Deepwater Port ops	13	5	0.10
Gas deliveries to SoCalGas	800	292	6.28
Total supply chain	1,038	379	8.15

Natural gas in million tonnes or the equivalent in LNG. Also see attached worksheets, Table 1.

[9] Exxon previously put Scarborough's recoverable gas reserves at 5 trillion cubic feet and "insufficient to sustain a world-scale LNG project." BHP recently completed an extensive reserve evaluation, and BHP and Exxon are now in closer agreement as to the field's reserves. An Exxon spokesperson stated that the company does not necessarily agree that "BHP's LNG plans [are] the best way to develop the reservoir." Wilson (2006); also see Freed (2006).

[10] The U.S. convention is to use mmcf for thousand thousand cubic feet. CMS adopts "M" as million, and "B" as billion, hence $MtCO_2$ for million tonnes CO_2 and Bcf for billion cubic feet. However, CMS avoids the use of both mmcf and Mcf, preferring to write it out to avoid confusion.

[11] That said, other gas sources might contain higher fractions of CO_2 (and vented to the atmosphere). Or it might require supplemental LNG shipments from other liquefaction plants, which would alter the LNG carrier propulsion estimates and perhaps the fleet size. Or BHP could buy LNG on the spot market. This analysis is based on the project as described in the BHP permit application. However, as we will discuss with the LNG plant below, BHP's plans are not adequate to supply the required amount of LNG to propel the requisite delivery rate to California.

The total production quantity determines each subsequent step, since emissions estimates are tied to, say, flaring rates at production platforms, or energy inputs to liquefaction, or the amount of LNG that has to be loaded and transported annually. This parasitic energy consumption drives emissions as well plant capacities and, for that matter, BHP's opportunities to improve plant efficiencies and profitability while also reducing the climate impact of its operations.

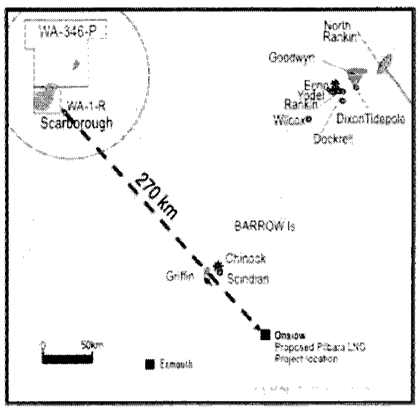
Emissions from gas production include gas flaring, methane leaks, platform energy requirements for compressors, power generation, heating loads, lighting, and hotel loads (for accommodation requirements such as hot water, ventilation, cooking, waste handling, and so forth).

Emissions related to gas production totals 0.79 million tonnes CO_2-eq ($MtCO_2$-eq), with 0.49 $MtCO_2$ of the total as combusted and vented carbon dioxide and 0.30 $MtCO_2$-eq as methane.

CMS' emissions estimates are based on reasonable and transparent protocols. Uncertainties are inevitable, in no small measure because these facilities have neither been designed nor built. CMS did not have access to BHP engineering data other than the scant information published in the permit application. CMS has assumed industry best-practice or, in some cases, improvements over standard practice or industry benchmarks. The assumption made throughout this analysis is that BHP will adopt the best-available technology and low-emission designs within economic and regulatory pressures. CMS makes low and high emissions estimates for each supply chain segment, and uses the average of the two in this summary report.

Natural gas transportation by subsea pipeline

The Scarborough subsea pipeline will transport about 370 Bcf of gas annually to Onslow, Western Australia, where BHP has selected a site to build its proposed Pilbara LNG plant (see the illustration on page 10). CMS estimates that 0.21 to 0.37 million tons of CO_2-eq will be emitted for pipeline energy needs, plus fugitive methane from leaky seals, compressors, and so forth. Methane leakage rates are based on U.S. data for gas production and transmission rates per Bcf of throughput. Since it is a subsea pipeline except for the production compressor station and onshore facilities, CMS reduced the industry gas transmission leakage rate by a factor of ten to five (low and high estimates, respectively).



Map of Scarborough natural gas field offshore Western Australia. BHP Billiton *Petroleum Review 2005*.

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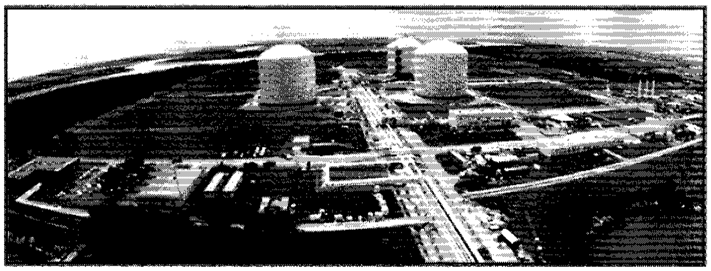
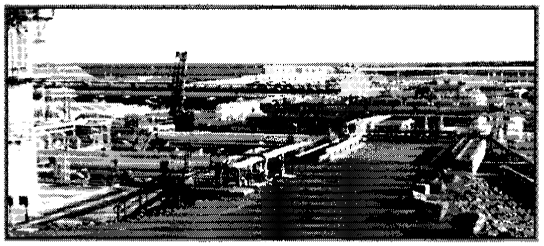
Pipeline compressor energy is the source of about half of the total pipeline emissions. CMS uses a conservative range in the pipeline energy estimate: forty and sixty percent *below* the U.S. industry average for the high and low estimates, respectively, since Scarborough is closer to the LNG plant than typical distances in the U.S. The industry rate is ~2.5 percent of gas throughput consumed for pipeline energy. If CMS had applied the common performance factor, 9.4 billion cubic feet of gas would be consumed for gas transportation, rather than the estimated 4.8 Bcf.

Gas liquefaction: proposed LNG plant at Onslow

Liquefaction is the preferred method for reducing the volume of natural gas in order to "economically" enable its long-distance transportation. Liquefaction also requires purification of the feed gas to remove natural gas liquids, CO_2, sulfur, and other contaminants that could corrode the steel tanks or impede liquefaction or otherwise not meet U.S. natural gas standards. Natural gas liquefies at a temperature of 259 degrees Fahrenheit below zero (-161 °C). Once liquefied, it has to be stored in heavily insulated tanks to minimize the heat transfer that would lead to excessive "boil off" — gasification or volatization — of the LNG. Liquefaction plants are typically built near shipping terminals, since most LNG is produced for international markets in Asia and Europe and, increasingly, the United States.



Unidentified LNG storage facility, presumably for peaking purposes. Source: US DOE (2005).

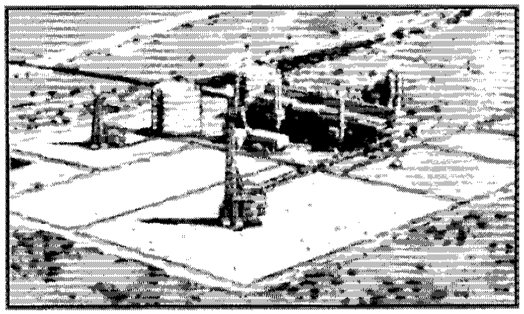


BHP North West Shelf natural gas processing plant. BHP Billiton *Petroleum Review 2005*.

CMS estimated the amount of LNG sufficient to (a) account for LNG boil-off during the 17-day trans-Pacific voyage and any additional propulsion or power generation requirements, including each vessel's return trip to Pilbara, (b) the amount of natural gas needed to operate the Cabrillo Deepwater Port, and (c) deliver the indicated amount of natural gas to SoCalGas. These estimates are shown in Table 2 above. If the Pilbara plant is sized to account for these parasitic loads and sufficient to deliver 292 Bcf of gas (equivalent to 6.28 million tonnes of LNG), the required plant size has to be increased from the 6 Mt/yr announced by BHP to 7.1 Mt/yr.[12]

BHP may elect to acquire additional quantities of LNG from other suppliers on the emerging spot market in order to satisfy its indicated delivery rate rather than increase the productive capacity of the Pilbara plant. This uncertainty is relatively immaterial to our principal objective, however, which is to estimate the supply chain emissions of greenhouse gases. Another plant may emit less or more CO_2 and methane, the feed gas may have a higher CO_2 content, but these are unknowns, and we have based our estimates on the most likely chain of events. This includes BHP's plans to construct an LNG plant at Onslow, use natural gas from Scarborough, and ship the LNG in a fleet of carriers to Cabrillo in southern California.[13]

BHP Billiton has not issued any design specifications on the proposed LNG plant. CMS thus does not have plant-specific emissions estimates to draw upon, nor are the selected liquefaction or electric generation or compressor technologies known. BHP has not yet issued a Feasibility report nor prepared an Environmental Impact Assessment. A sketch of the proposed plant based on BHP's site-selection study is reproduced below.



An artist's sketch of the proposed Pilbara LNG plant at Onslow. Source: BHP *Pilbara News*.

In lieu of actual process and technology specifications, CMS used emissions factors for a state-of-the-art facility operated by ConocoPhillips at Darwin, Australia. The Darwin plant uses the Phillips Cascade Process for liquefying natural gas, is a single-train 3.24 Mt/yr plant with one large cryogenic storage tank, and emits an estimated 1.4 million tonnes of carbon dioxide and methane per annum.[14] The CMS methodology for using Darwin's emissions rates involved several steps, each detailed in the attached worksheets:

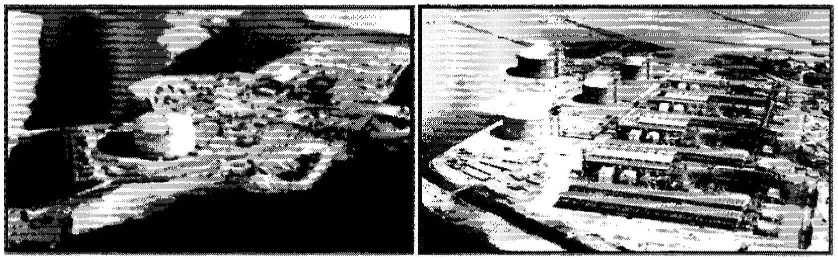
[12] The Pilbara plant will consume ~37 Bcf of gas from Scarborough in the process of liquefying 7.1 Mt/yr of LNG. While many LNG plants use propane and other natural gas liquids contained in the feed gas, BHP has not provided an analysis of the Scarborough, and CMS has converted the LNP plant's energy requirements to equivalent gas.

[13] Due to the trans-Pacific voyage, BHP will need a fleet of 11 LNG carriers. Assumptions: 138,000 m^3 carriers, gas mode on 60,000 HP Wärtsilä 50DF engines (consuming 6,740 m^3 one way), 7,900 nautical miles each way, vessel speed of 19.5 knots, and a 24-hour turn-around at each terminal. A current cost of $160+ million per carrier suggests a "pipeline" investment of $1.76 billion. Diesel-only fuel mode would increase net deliverable LNG by 13,500 m^3 per trip (assuming full re-liquefaction of boil off gas) and reduce the fleet size by one carrier and $160 million.

[14] The Darwin plant delivers LNG to Tokyo Electric and other Japanese project partners. The first shipment to equity partners Tokyo Electric and Tokyo Gas occurred in Feb06. Emissions are based on estimates (with planned mitigation measures), not measurements, and are drawn from ConocoPhillips (2005) *Operations Env. Mngt Plan*.

1. Scale Darwin's emissions by a factor based on actual LNG requirements for Pilbara, which was in turn increased from BHP's estimated plant size (6.0 Mt/yr) to CMS' estimate that 7.07 Mt/yr of capacity is required in order to deliver 800 million cubic feet of gas to Cabrillo. The resulting scaling factors is thus: Darwin = 3.24 Mt/yr and Pilbara = 7.07 Mt/yr for a ratio of 1:2.18;[15]
2. The scaling factor was applied to Darwin's emissions rates per tonne of LNG produced, except for two important adjustments: (a) Darwin's feed gas (from the Baya-Undan gas field 500 km offshore) contains six times more CO_2 than BHP's Scarborough gas, (b) the electricity required to operate acid gas venting process is thus also reduced. Both of these factors are accounted for;
3. The Pilbara "low" emissions estimate is based on Darwin's emissions rates multiplied by the scaling factor between the two plants (and adjusted for the lower carbon content of gas feed, as noted above);
4. The Pilbara "high" estimate is based on a blended emissions factor, averaging Darwin's unusually low emissions rate (0.43 tonnes CO_2-eq per tonne of LNG produced) and the recently completed Train #4 at Atlantic LNG Company of Trinidad and Tobago (0.81 tCO_2-eq/tLNG). This higher emissions factor is again adjusted for Scarborough's lower CO_2 content feed gas.
5. Also, in the Pilbara "high" estimate, the methane venting rate has been increased from Darwin's rate to that of U.S. natural gas industry average in 2004.[16]

CMS estimates both "high" and "low" emissions for the scaled-up Pilbara LNG plant for refrigeration compressors (which, due to their very large size and constant operation, require enormous inputs of site-generated power), other plant electricity demands, acid gas venting (removal of carbon dioxide from the feed gas prior to liquefaction), nitrogen rejection units, flaring from numerous sources at the LNG plant, terminal, and loading operations), methane vented directly to the atmosphere, and minor amounts of nitrous oxide emissions. The "low" estimate totals 1.97 million tonnes of CO_2-eq per year, the "high" estimate totals 3.41 $MtCO_2$-eq/yr, and an average of 2.69 Mt $MtCO_2$-eq/yr. Methane from venting and incomplete combustion is 5.6 to 7.0 percent of total LNG plant emissions.



The Darwin LNG plant, 3.24 Mt/yr, *left*, & the Atlantic 4-train LNG plant, 15 Mt/yr, *right*.

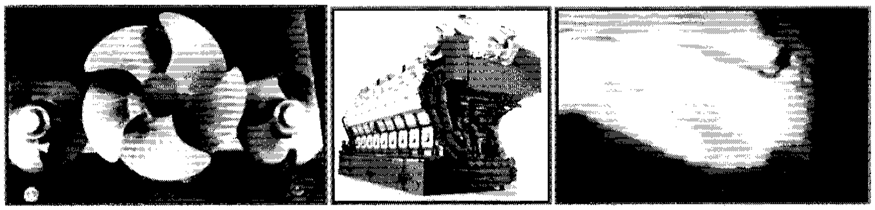
[15] This assumes that BHP adopts the ConocoPhillips design, liquefaction process, state-of-the-art technology, and mitigation efforts. CMS cannot ascertain that BHP will select these technologies, nor meet or exceed the Darwin plant's emissions reduction initiatives — such as high-efficiency aero-derivative gas-fired turbines to power refrigeration compressors, waste heat recovery, ship vapor recovery, efficient pumps and motors, and cascading emissions benefits from smart design and technology.

[16] ConocoPhillips (2005) *Darwin OEMP*, note to Table 5.2: "A routine venting operation. .... The methane emission rate is 268.8 kg/h with duration of venting assumed to be 7,671 hours per year." CMS has updated the GWP factor from 21 to 23xCO_2, per IPCC's *TAR* report (2001), p. 388. Using the scaling factor applied to compressors (based on the Atlantic Train #4 relative to the Darwin emissions rate) results in a methane emissions estimate of 6,604 tonnes of CH_4. CMS instead applies the methane emissions rate of the US natural gas processing industry (Table 11 in the attached worksheets), namely 28.22 tonnes of CH_4 per Bcf of natural gas consumption, which, in the case of the scaled-up Pilbara plant, totals 366 Bcf per year (see worksheet Table 1).

LNG shipping via fleet of LNG carriers

LNG carriers are traditionally powered by steam turbines burning marine diesel or heavy fuel oil. The new generation of LNG carriers are increasingly installing diesel-electric propulsion systems in which two to four large engines generate electricity that power electric drives. Dual-fueled engines, such as those made by Wärtsilä that CMS has based its propulsion and emissions estimates upon, can burn either marine diesel/heavy fuel oil and/or natural gas — the source of which is the boil-off gas from the cargo. Emissions from this segment of the LNG supply chain are the result of converting propulsion fuel into carbon dioxide (plus some methane).

CMS based its fuel consumption estimates on statements in the CSLC (2006) *Revised Draft EIR*. Although BHP has "not finalized design specifications for LNG carriers" or determined (to our knowledge) the size, propulsion type, or fuel preference, CMS used the lower end of the vessel size (138,000 m^3) cited, modeled emissions and fuel consumption for three scenarios (low, medium, and high), and derived total annual trips based upon the same basic criterion followed throughout this exercise: the delivery of 800 million cubic feet of gas daily (292 Bcf/yr) to southern California markets.[17]



Propellers, 50DF dual-fueled engine, and a bulbous bow plowing through pacific waters. www.wartsila.com

The BHP permit application cites a power rating of 60,000 HP (44.7 MW), and while this is higher than the propulsion rating of other ships of similar size,[18] CMS has used the BHP-supplied data for the calculations.[19] Furthermore, CMS assumed the use of Wärtsilä 50DF duel-fuel engines as power plants, with CO_2 emission rates of 430 to 630 grams of CO_2 per kWh, depending on fuel type.

[17] CSLC (2006) *Rev Draft EIR*, p. 2-21: "LNG carriers would have a capacity ranging from 36.5 to 55.5 million gallons (138,000 to 210,000 m^3). Of this volume, an estimated 4 million gallons (15,100 m^3) would be consumed by the carrier while in transit for fuel and for maintaining the cold tanks; the remaining 32.5 or 51.5 million gallons (123,000 or 195,000 m^3) would be transferred to the FSRU. LNG carriers would be powered by natural boil-off gas from their LNG cargo, as agreed with the U.S. Environmental Protection Agency (USEPA) (Klimczak 2005). The Applicant has not finalized design specifications for LNG carriers; therefore, the diesel storage capacity for LNG carriers cannot be estimated at this time."

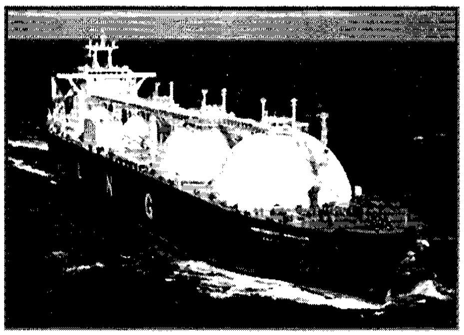
[18] Küver et al (2002) "Evaluation of Propulsion Options for LNG Carriers," show the predicted power requirement — albeit for propulsion only — of a state-of-the-art LNG carrier of 145,000 m^3 size cruising at 19.5 knots (as we assume here) as ~25 MW, not the 44.74 MW used by BHP. Küver also models the boil-off rate (0.15% BOG/d) vs fuel requirement for a 142,000 m^3 carrier, which consumes its full boil-off rate of 100 tonnes/day at 19.5 knots, thus requiring no re-liquefaction and no supplementary diesel fuel consumption.

[19] Either BHP is including high auxiliary power requirements — for other ship functions, hotel loads, and possibly powering re-liquefaction compressors so as to deliver the maximum cargo to Cabrillo as opposed to using the boil-off gas as engine fuel — or BHP will reduce the expected ships' power rating, or increase the vessel size. Resolving this conflicting information may justify a re-calculation of the fuel type and quantity for the LNG trade route. Note: If BHP was planning to use the next-generation carrier size (up to 250,000 m^3), its fleet would to make fewer than the stated ~"2.5 deliveries per week" (BHP, p. 3-5).

Assuming Scarborough/Pilbara as the origination of the gas and LNG, CMS estimates a trade route of 9,100 miles, or 7,908 nautical miles, each way. LNG carriers recently delivered from shipyards typically achieve 19.5 knots (though this will vary by trade route).[20] means a voyage of 406 hours, or almost 17 days en route. CMS modeled three fuel scenarios as follows:

1. Gas-only mode that used LNG boil-off gas plus an additional quantity of vaporized natural gas sufficient to fuel the engines: 430 gCO_2/kWh times 18.1 million kWh for each one-way trip = 7,800 tonnes of CO_2, consuming 6,740 m^3 of LNG en route;
2. Duel-fuel mode that burned boil-off gas at the normal rate supplemented with diesel fuel at 630 gCO_2/kWh, which means a blended rate of 529 gCO_2/kWh ⇨ 9,590 tonnes of CO_2 and the consumption of 3,420 m^3 of LNG en route (of which the boil-off gas, at 0.15 percent per day, would supply approximately 54 percent of the required fuel);[21]
3. Diesel-only mode at 630 gCO_2/kWh resulting in 11,430 tonnes of CO_2 for each one-way trip, with zero LNG consumption. Note: this assumes re-liquefaction of the boil-off gas,[22] which requires on-board compressors and a power requirement of up to 3.5 MW (Roger Courtay, quoted in *Naval Architect*, Nov03). Ship design aside, BHP's blue-water fuel option will most likely be driven by fuel costs versus the value of the additional deliverable cargo, not emissions.[23]

These three options become the "low," "medium," and "high" emissions scenarios. Annual low emissions totals 1.80 million tonnes of CO_2-eq ($MtCO_2$-eq), with 112 loads of LNG delivered (2.2 berthings per week). The medium estimate totals 2.09 $MtCO_2$-eq, and 107 berthings per year. The high emissions estimated totals 2.37 $MtCO_2$-eq, with 101 berthings per year. CMS based its gas production estimate at Scarborough plus the Pilbara liquefaction capacity on the gas-only propulsion fuel mode cited in the CSLC *Draft EIR* (p. 2-21, quoted above) and its reference to consuming a large quantity of LNG boil-off gas en route. The quantity of natural gas consumed for the LNG carrier operations totals 32 Bcf per annum, which is equivalent to 0.69 million tonnes of LNG per year. (See Table 2 above and the attached worksheet Tables 1, 7, 8 and 9 for details, calculations, assumptions, documentation, and results.)


An LNG carrier with Moss spherical tanks shown in BHP literature.

[20] Colton, Maritime Business Strategies (2006), www.coltoncompany.com

[21] As noted in footnotes on the previous page, BHP is probably in error in citing a 60,000 HP vessel. Küver et al (2002) show that a 142,000 m^3 carrier with diesel-electric propulsion will theoretically consume its BOG at 19.5 knots (albeit, for propulsion only). CMS estimates may be revised with updated or more complete BHP data.

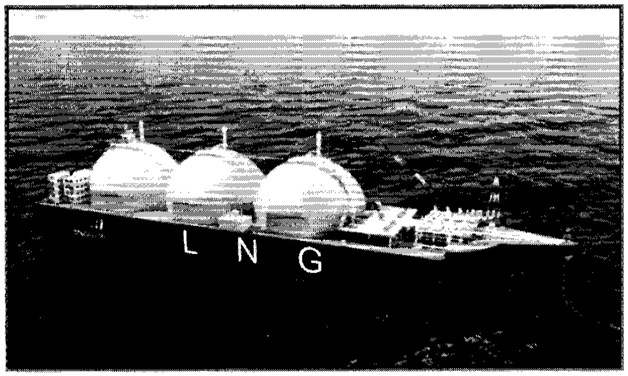
[22] In the high emissions scenario the LNG is reliquefied onboard in order to maximize the amount of LNG delivered. See Lunde (2005). Hamworthy is a leading proponent and systems vendor for this concept. www.hamworthy.com

[23] BHP has stated that its LNG carriers will burn only natural gas while in Federal waters. CLSC *Revised Draft EIR,* pp. 4.6-15, 16, 34, states that the LNG tankers will run "primarily on natural gas" within 25 miles of shore.

LNG terminal: Cabrillo Deepwater Port

Next, CMS used BHP-supplied data on the amount of natural gas needed to operate the Cabrillo Deepwater Port, including gas used to generate electricity on board the LNG carriers that power pumps to transfer 57,000 to 63,000 tons of LNG from the carrier to the FSRU (at a design rate of 65,000 gallons per minute). CMS also included fuel consumption for tenders, tugs, and crew boats, and natural gas burned in the four (of eight) constantly operating 115 million Btu/hr vaporization units on the FSRU.[24] Electricity also has to be generated to run the FSRU's cranes and booms, waste transfer pumps, water pumps as well as hotel loads such as water heating, ventilation, cooking (for a crew of 30 to 50 persons), lighting, and electronic equipment. Other emissions sources include methane from incomplete combustion of fuel.

The generating capacity onboard the FSRU totals 25 MW and is to be provided by four Wärtsilä 9L50DF duel-fuel generators.[25] BHP's own emissions estimate from the sources listed above totals 0.26 million tonnes CO_2-equivalent per annum (including 39 tonnes of methane). BHP also estimated Start-Up emissions for the break-in phase of the Cabrillo Port totaling 0.01 milllion tonnes of CO_2-eq.



Sketch of the Cabrillo Deepwater Port Floating Storage and Regasification Unit (FSRU). Source: BHP.

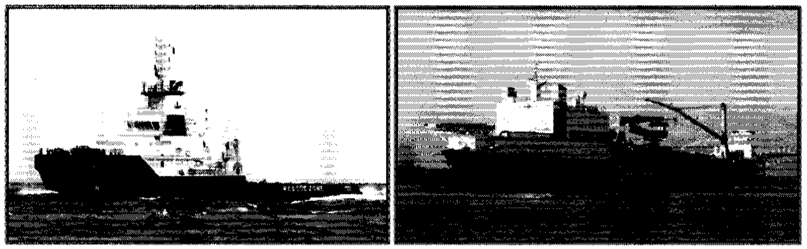
CMS adopts BHP's emissions estimate as the "low" estimate. The CMS "high" estimate totals 0.43 $MtCO_2$-eq for the annual operating emissions (plus 0.02 $MtCO_2$-eq for Start-Up) by adding fugitive methane from the FSRU operations (note: BHP estimated methane from incomplete combustion but did not estimate fugitive methane; CMS applies BHP's cited methane rate [0.39 gCH_4/HP-hr] to BHP's trans-Pacific LNG carrier trade route). Since there is growing pressure on operators and engineers to reduce both flaring and venting at FPSOs and FSRUs, CMS lowers the benchmark methane emission rate by applying one-half of the average U.S. gas industry

[24] This is an impressively large operation. The FSRU is 970 feet long and covers about four acres (see image above). The LNG re-gasification units have a combined heat rate of 460 million Btu/hr — sufficient capacity to heat the homes in a mid-sized mountain town in winter — in order to heat and vaporize ~800 tons/hour of the cryogenic liquid from -259°F to 41°F.

[25] Three Wärtsilä gen-sets of 8.3 MW plus one back-up generator; each will typically be fueled with natural gas but capable of running on diesel whenever required, e.g., in emergency natural gas curtailment situations. BHP (2005), section 2.2.

leakage rate for gas processing facilities. Presumably, BHP's FSRU will achieve a lower rate than typical gas processing facilities, but BHP supplies no estimates of its own and CMS does not have access to measured data from such facilities. CMS applies a reasonable estimate in lieu of BHP- or CSLC-published estimates.[26]

In addition, CMS estimates that the six-month FSRU construction phase will consume ~1.1 million gallons of diesel and marine diesel fuel and emit 0.01 $MtCO_2$-eq for pipelaying and related construction activities. This involves a flotilla of pipe-laying vessels and barges and tenders and crew boats for the construction of the twin 24-inch subsea natural gas pipelines connecting the FSRU to onshore gas networks, as well as an armada of trucks and trenchers and dozers and backhoes for the pipelines' shore crossing and utility-connections. Construction emissions are added to Cabrillo's Start-Up phase, and both the "low" and "high" emissions estimates for Start-Up are added to Cabrillo's operational emissions by annualizing Start-Up over a 25-year period.[27]



Anchor handling tug *Primus* of Antigua, left, and pipelaying vessel *Solitaire* of Panama, right.
Source: Maritimephoto.com, with permission.

Ultimate consumption of the gas delivered to California customers

The largest component of the supply chain emissions is, not surprisingly, the combustion of the natural gas delivered to SoCalGas and distributed to the utility's customers. While a common benchmark is to estimate carbon dioxide from complete combustion of the natural gas delivered, CMS makes two adjustments. First, we deduct small amounts of gas diverted to other, non-fuel uses, and are consequently sequestered into other products rather than combusted to CO_2 and emitted to the atmosphere; secondly, we deduct a small fraction to account for the small

[26] BHP has estimated emissions of methane from incomplete combustion of natural gas used in the equipment categories listed in Table 10 of the attached worksheets. The BHP estimate, as far as we can ascertain, does not include fugitive emissions of methane from leaky pipes, valves, flanges, tanks, seals, and other fuel containment systems. CMS has not evaluated the legal requirement to estimate additional methane emissions, nor can CMS make an engineering estimate of such emissions. CMS does attribute one-half of the emissions rate from natural gas processing (0.5 * 28.22 tonnes CH_4/Bcf) plus one-tenth of methane emissions from gas distribution and storage (0.1 * 105.73 tonnes CH_4/Bcf) as an indicator that a Cabrillo-specific emissions estimate must be made. These rates are applied to total natural gas throughput (292 Bcf delivered to SoCalGas plus 5 Bcf required for Cabrillo operations).

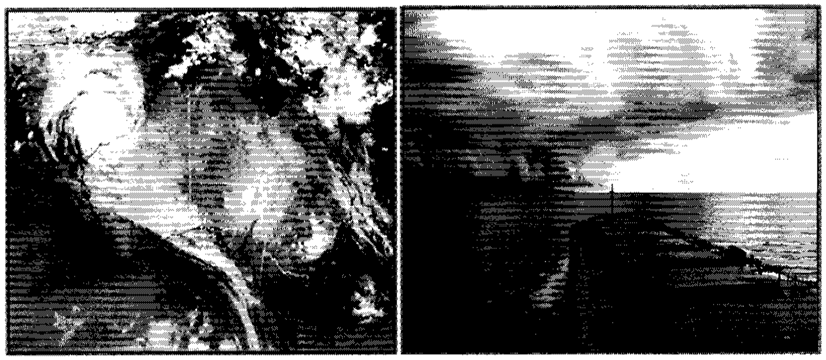
[27] While a 25-year time horizon may be shorter than total anticipated project lifetime (40 years is mentioned in the CLSC *Draft EIR*), it is close to the 21.1-year life-expectancy of Scarborough gas field, assuming that the identified 8.0 trillion cubic feet of reserves are produced at an annual rate of 379 Bcf/yr detailed Table 2 above. This annual production rate accounts for the gas delivered to SoCalGas by BHP as well as the gas consumed at the Scarborough gas platform, in the 270-km subsea pipeline to the Pilbara LNG plant, for liquefaction and LNG plant use, gas consumption by LNG carriers, and gas requirements of the Cabrillo FSRU. Without these adjustments, the 800 million cf of gas per day deliverable to SoCalGas equals 292 Bcf/yr, or a simple 27-yr depletion schedule.

proportion of the fuel that is not combusted into CO_2. The first calculation is based on U.S. non-fuel uses of natural gas, although southern California's end-use gas consumption patterns likely differ somewhat from the nation as a whole, whereas the second is based on default values used by the U.S. EPA and the IPCC inventory protocols.

Non-fuel uses of natural gas are chiefly for fertilizer and methanol production and averages about three percent of total U.S. natural gas consumption. An analysis by CMS shows that the actual sequestration rate must also account for the proportion of non-fuel uses that is relatively quickly returned to the atmosphere as greenhouse gases; methanol, for example, is used in transportation, and fertilizer production emits both nitrous oxide and CO_2. Once adjusted, the sequestration rate is reduced from 3.05 to 0.3 percent of total natural gas consumption.

According to EPA and IPCC inventory guidelines, 0.5 percent of natural gas in the combustion stream is not combusted to CO_2. Finally, a methane leakage rate is applied to gas distribution based on typical leakage rates in the natural gas industry. See the worksheet Table 12 for details.

The "low" and "high" estimates are numerically close, given the small variability applied to combustion emissions minus "sequestered non-fuel uses" and "non-combusted" fractions. The emissions estimates range from 15.82 to 15.89 $MtCO_2$ plus 0.58 to 0.72 $MtCO_2$-eq of methane for an average total "gas distribution and combustion" estimate of 16.50 $MtCO_2$-eq per year.



Cyclone Glenda satellite image hours after it pummeled Onslow, Western Australia (site of BHP's proposed Pilbara LNG plant) with 176-mph winds on 30Mar06, left; bulk carrier *Graham* facing a cyclone at sea, 2002, right.

Summary

A full accounting of emissions of greenhouse gases arising from the supply chain linked to BHP Billiton's proposed LNG receiving terminal has been presented. Contrary to BHP's submitted emissions estimates — which included only emissions from the Cabrillo Deepwater Port operations — CMS has included emissions from the natural gas production platform offshore Western Australia, transportation by subsea pipeline to the emissions-intensive onshore liquefaction plant, followed by shipping in a fleet of LNG carriers across 7,900 nautical miles of Pacific Ocean, receiving and regasification at the Cabrilllo terminal 14 miles offshore Ventura and Los Angeles Counties, and finally combusted by gas customers in southern California. All of these steps are required to deliver the quantity of natural gas premised in the BHP *Construction Permit Application* filed with Federal agencies and the State of California Lands Commission.

Table 3: Supply Chain emissions: low estimate

Supply-chain segment	Methane	Carbon Dioxide	Total	Percent
	thousand tonnes of CO_2-eq			
Gas production (Scarborough)	254	400	654	3.1%
Gas pipeline to Pilbara LNG	90	211	301	1.4%
Liquefaction plant at Onslow	110	1,855	1,965	9.2%
LNG carrier fleet, Australia → California	44	1,755	1,799	8.4%
Cabrillo Deepwater Port Operations	0.9	261	261	1.2%
Cabrillo Start-Up (annualized, 25yrs)	negl	0.4	0.4	0.0%
Ultimate gas distribution & combustion	578	15,815	16,393	76.7%
Total supply-chain GHG emissions	1,078	20,300	21,378	100.0%
Percent	5.0%	95.0%	100.0	

Table 4: Supply Chain emissions: high estimate

Supply-chain segment	Methane	Carbon Dioxide	Total	Percent
	thousand tonnes of CO_2-eq			
Gas production (Scarborough)	339	589	928	3.8%
Gas pipeline to Pilbara LNG	181	317	497	2.1%
Liquefaction plant at Onslow	239	3,169	3,409	14.1%
LNG carrier fleet, Australia → California	49	2,320	2,369	9.8%
Cabrillo Deepwater Port Operations	169	261	431	1.8%
Cabrillo Start-Up (annualized, 25yrs)	negl	0.4	0.5	0.0%
Ultimate gas distribution & combustion	722	15,888	16,610	68.5%
Total supply-chain GHG emissions	1,699	22,548	24,248	100.0%
Percent	7.0%	93.0%	100.0	

Note: BHP Billiton's estimate of annual emissions at Cabrillo totals 261 thousand tonnes CO_2-eq.
Note: Tables 3 and 4 are in metric tonnes (1 tonne = 1.1023 short tons).

Conclusions

The supply chain emissions analysis summarized in this report provides a superior measure of the proposed Cabrillo Deepwater Port's impact on the global climate. No energy supply project of the scale proposed by BHP Billiton is without substantial emissions of greenhouse gases in every critical link of the supply chain.

There is no satisfactory rationale for ignoring emissions arising from the proposed supply chain — without which the project is infeasible — in an environmental impact report.

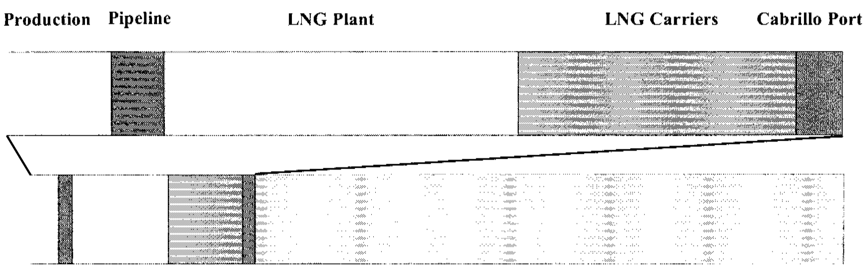
The accuracy of CMS's estimates can be improved with contributions and data-sharing by both the proponent and the State of California Lands Commission. CMS uses conservative estimation procedures, performance benchmarks, and emissions factors, and each step of the calculations is fully documented and transparent. Considerable uncertainties are unavoidable in an analysis with so many unknowns. BHP's documentation of the planned supply chain is sparse, and BHP only estimated emissions the Cabrillo Deepwater Port segment.

Moreover, technological change is rapid in the fast-growing LNG sector: operators are under pressure to market stranded natural gas from offshore fields. Also, public and regulatory pressures increasingly mandate emissions mitigation measures, especially regarding the transport, storage, and processing of LNG. The private sector can profit handsomely from increasing efficiency and trading emissions. Finally, the Cabrillo Port and its requisite supply segments will not be completed until 2011 or later. All of these factors suggest considerable evolution of the technologies deployed along the entire supply chain. Given these uncertainties, the CMS estimates of emissions from the BHP supply chain must be regarded as preliminary and subject to improvement with access to better engineering data as the project matures.

The BHP estimate, echoed by California State Land Commission's *Revised Draft Environmental Impact Report*, concludes that the project's emissions of greenhouse gases are "insignificant" and "represent less than 0.06 percent of the ... emissions produced in California in 2002."[28]

CMS results show a different picture, with the supply chain emissions from production through end-use of the delivered natural gas equal to 4.3 to 4.9 percent of California's total GHG emissions, and 5.3 to 5.9 percent of CO_2 emissions using Energy Information Administration state emissions data.[29] Broadening the comparison — again accounting for emissions from production in Australia to combustion of the gas delivered to end-use customers in California — shows that emissions from BHP's proposed LNG project are equivalent to 0.30 to 0.34 percent of total U.S. emissions (using EIA data for 2004). BHP's estimated emissions from its operation of the Cabrillo Deepwater Port comprises a mere 1.5 percent of emissions from the entire supply chain. This relationship is shown in Figure 2, with the Cabrillo emissions in red.

Figure 2. Bars showing relative emissions contributed by each supply chain segment



[28] CSLC, p. 4-20: "Project operations would cause annual CO_2 emissions of 0.29 million tons per year (MMtons/yr). Project start-up and construction activities would result in one-time CO_2 emissions of 0.010 MMtons and 0.017 MMtons, respectively. These emissions represent less than 0.06 percent of the 543 MMtons of CO_2-equivalent greenhouse gas emissions produced in California in 2002 (CEC 2005). The greenhouse gas emissions from the Project would be insignificant alone, but could exacerbate, in combination of existing greenhouse gases, global warming effects."

[29] Using the cited CEC emissions data for all greenhouse gases in 2002. Supply chain CO_2 emissions comprise 5.27 to 5.84 percent of California's CO_2 emissions in 2001 (EIA data).

Another notable result of the CMS study is that the supply chain adds 35 to 53 percent to the common way of measuring emissions from natural gas consumption, namely the combustion of the gas itself, disregarding the supply chain emissions. This is the LNG supply chain "adder," although it must be emphasized that we have not estimated ancillary emissions from other natural gas supply alternatives — such as the Long Beach or Baja Mexico LNG proposals, sources of domestic gas by pipeline from Texas or Colorado, or, for that matter, coal-fired electric generation, renewable electricity options, or end-use efficiency of any and all uses of natural gas in California.[30]

Consequently, the results presented in this report do not argue for or against the proposed LNG project. Instead, the objective has simply been to fill the analytical gap left by BHP Billiton's and CSLC's omission of estimating the emissions from the remainder of the required natural gas supply chain.

[30] See, for example, Hunt et al (2006), Lovins et al (2004), and Lovins et al (forthcoming late 2006).

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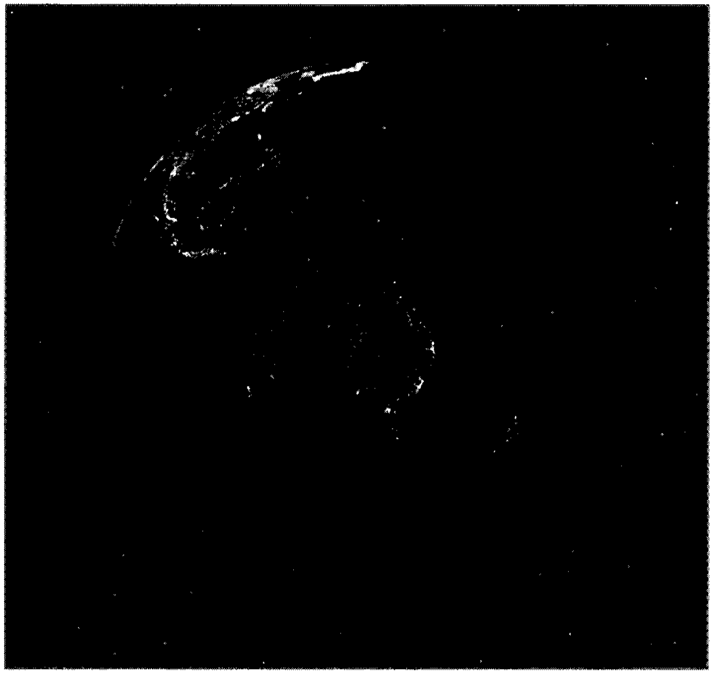
Conversions[31]

Table of conversions		
1 tonne LNG	46,467	cubic feet gas
1 cubic meter LNG	21,189	cubic feet gas
1 cubic meter LNG	0.4560	tonne LNG
1 tonne LNG	2.1930	cubic meter LNG
1 tonne LNG	51.1138	million Btu
1 cubic meter LNG	23.3079	million Btu
1 million cubic feet gas	21.5206	tonnes LNG
1 million cubic feet gas	47.1943	cubic m LNG
1 nautical mile	1.1508	statute miles
1 horsepower (HP)	0.7457	kW
1 kW	1.3410	horsepower (HP)
1 million cf gas per day	7,885	tonnes LNG per yr
1 tonne	1.1023	short (US) tons
1 kg	2.2046	lb
1 cubic meter	35.3147	cubic feet
Combustion of 1 Bcf	54,602	tonnes CO2
1 tonne CO2	18,314	cubic feet gas
Combustion of 1 m^3 LNG	1.1570	tonnes CO2
Combustion of 1 tonne LNG	2.5372	tonnes CO2

[31] Conversion sources: U.S. Dept of Energy (2005) *Liquefied Natural Gas: Understanding the Basic Facts*, p. 9; miscellaneous engineering sources; and calculations by CMS.



A portion of the LNG trade route from NW Australia to southern California,
around the edge of Earth's disk at ~2 o'clock.

Notes

LNG Supply Chain GHG Emissions: Australia to California

Folio of worksheets

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All emissions estimates are annual

Table 1	Total gas production required to deliver 800 million cf/day
Table 2	Emissions from gas production at Scarborough platform
Table 3	Emissions from transporting produced gas to Pilbara LNG plant
Table 4	Emissions from liquefaction at the proposed LNG plant
Table 5	Upsizing the Pilbara LNG plant to that required for delivery
Table 6	Comparing production and GHG emissions from several LNG trains
Table 7	Shipping details: distance, vessel speed, and journey duration
Table 8	Emissions for each LNG carrier from Onslow to Cabrillo (one way)
Table 9	Emissions from BHP's presumed LNG carrier fleet, per annum
Table 10	Emissions from Cabrillo Deepwater Port, including regasification
Table 11	Methane emissions rate from the US natural gas industry
Table 12	Emissions from gas distribution and combustion (net of seq.)
Table 13	LNG Supply-Chain Emissions Summary - Low Estimate
Table 14	LNG Supply-Chain Emissions Summary - High Estimate
Table 15	Average of Low and High Supply-Chain Emissions
Table 16	Comparing total LNG Supply-Chain to US and California emissions

Tables 1-16 on four sheets, with cell comments, sources, formulae, caveats, and discussion on the following sixteen pages.